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Ross Wagnild, Joseph Jewell, Ivett Leyva, Graham Candler, Joseph Shepherd

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4 Draco Drive.
Edwards AFB CA 93524-7160

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14. ABSTRACT
This effort is focused on using linear stability analysis (PSE) and Navier-Stokes solvers to study the effect of non-equilibrium effects, present in high-enthalpy flows, on 2nd mode disturbances and transition. The effort is concentrated on flows over slender cones with air, CO_2, and mixtures of those two gases as the test gases.

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Computational Analysis of High Enthalpy Effects on 2nd Mode Disturbances

Ross Wagnild, Sandia National Labs

Joseph Jewell, Caltech, Ivett Leyva, AFRL, Graham Candler, University of Minnesota, Joseph Shepherd, Caltech

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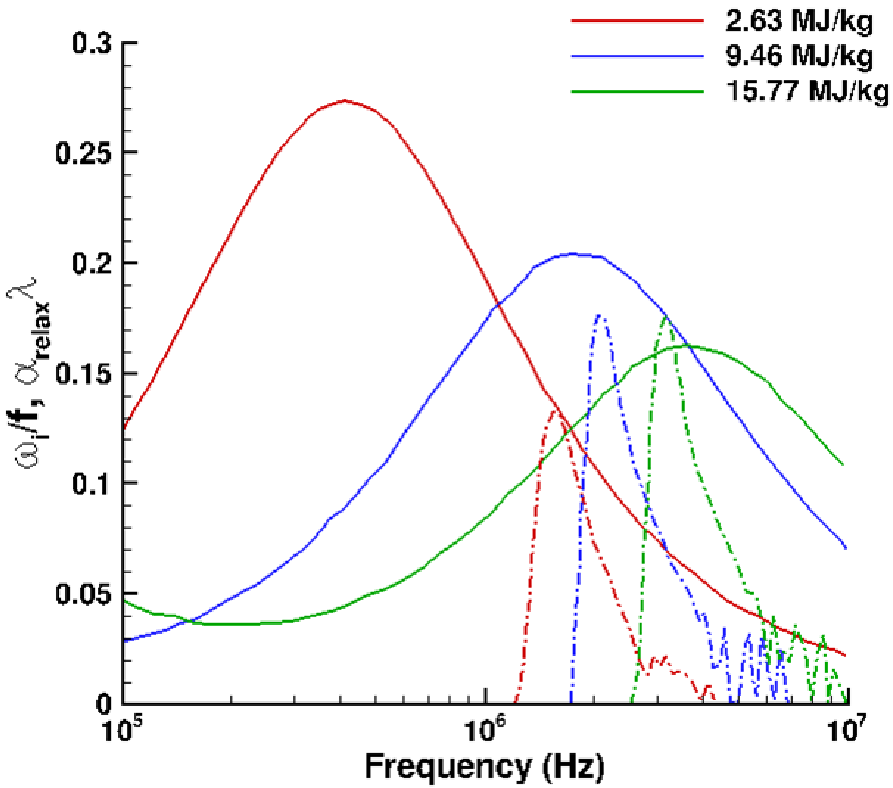
Sandia National Laboratories

Introduction

- Transition on slender, constant-angle cones
- Fujii and Hornung
  - Investigated acoustic damping in equilibrium mixtures
- Jewell et al.
  - Porous injection of CO_2 into a hypervelocity boundary layer on a sharp cone



Amplification and absorption over a range of frequencies in CO_2

Previous work

- Modeling T5 shock tunnel experiments
  - 5° half-angle sharp cone
  - Smooth and injection inserts
  - Air, N_2, and, CO_2
  - $h_0 \sim 4 - 10.5\ MJ/kg$
  - $P_{res} \sim 30 - 85\ MPa$

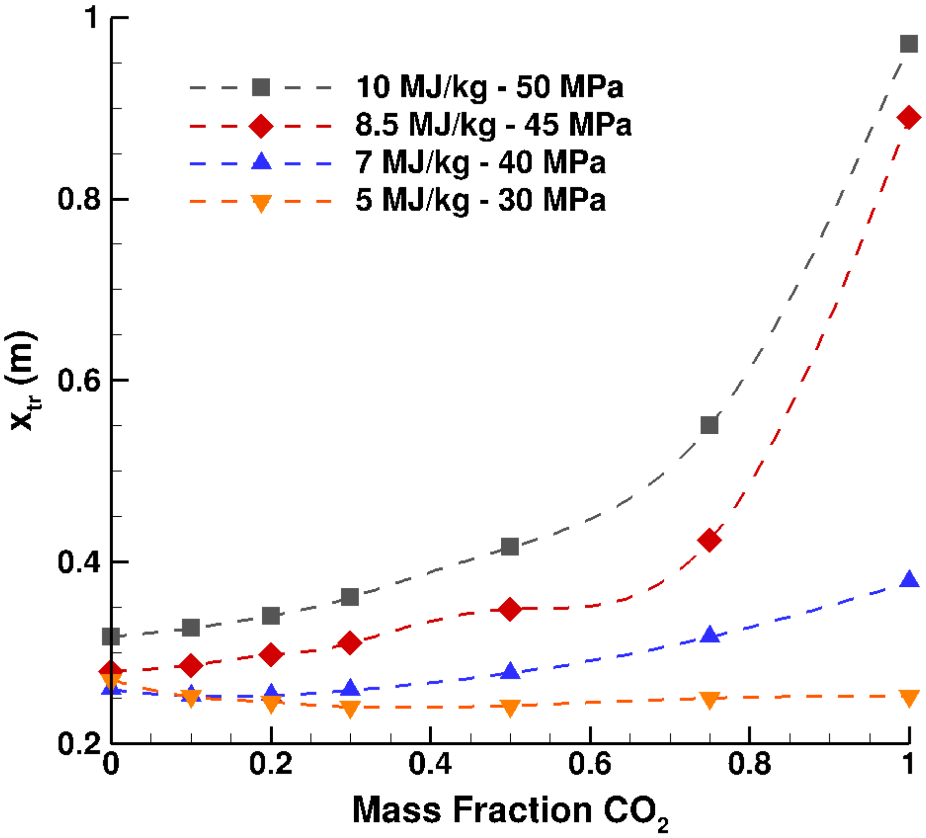
Test cone used in T5 tunnel experiments

Computational Tools

- Tunnel Flow
  - Nozzle Code + STABL CFD solver
    - 2D and axi-symmetric, reacting Navier-Stokes
    - Second-order accurate fluxes
    - High-pressure, excluded-volume equation of state
  - US3D
    - Solves 3D, reacting Navier-Stokes Equations
    - Inviscid fluxes are formulated for low dissipation
    - Viscous fluxes are second-order accurate
    - Implicit time advancement up to second-order accurate
    - High-pressure, excluded-volume equation of state
- Stability Analysis
  - PSE-Chem
    - Solves the axi-symmetric linear PSE
    - Includes finite-rate chemistry and T-V energy exchange

Current Efforts:

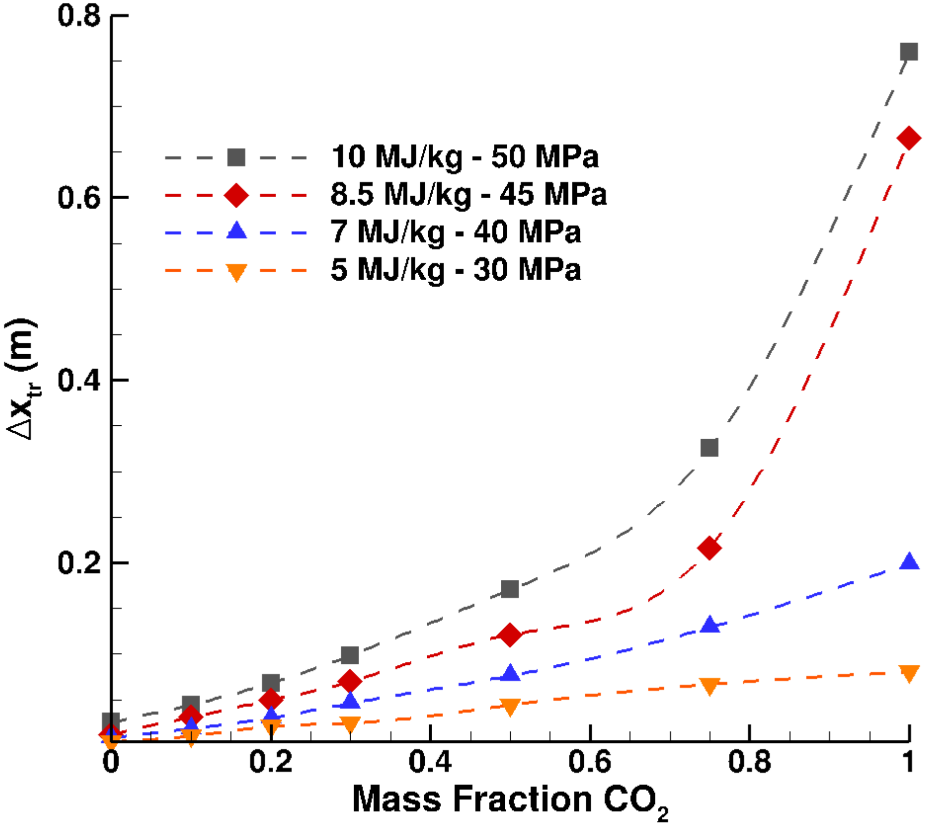
- Freestream Mixtures
  - Air + CO_2
- Prediction Goals
  - Large transition delay in T5
  - Ensure effective application of damping
    - "Freezing" vibration in PSE stability analysis



Predicted transition of T5 experiments using N = 5

Current Efforts:

- Freestream Mixtures
  - Air + CO_2
- Prediction Goals
  - Large transition delay in T5
  - Ensure effective application of damping
    - "Freezing" vibration in PSE stability analysis



Change in transition location due to vibrational damping

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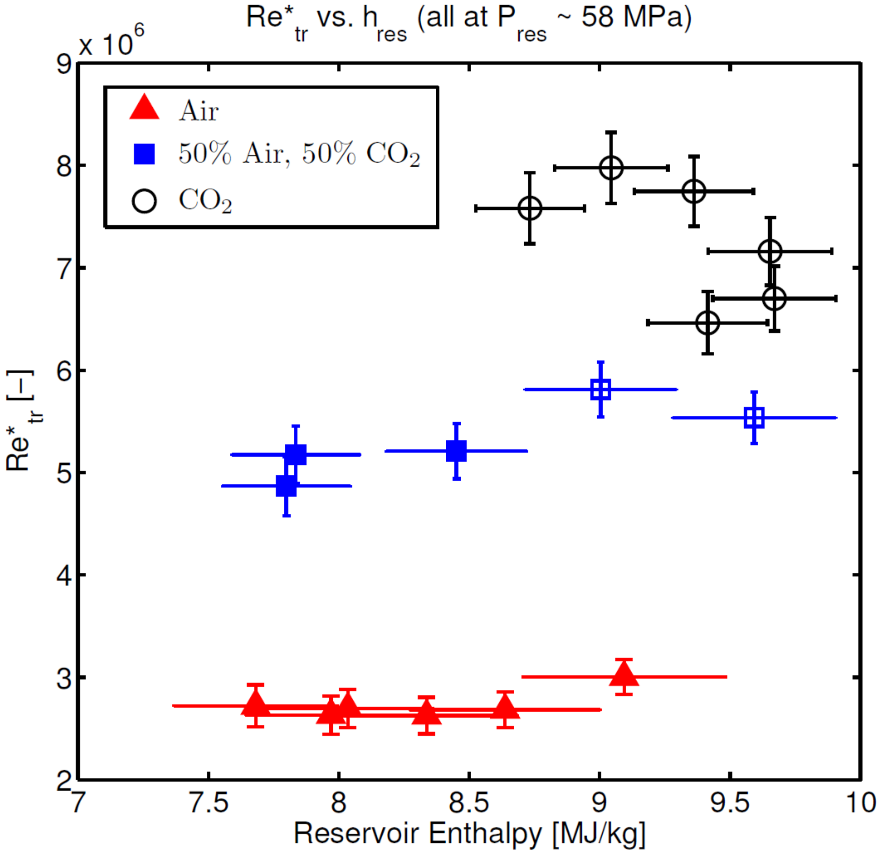
Current Efforts

- Experiments
  - Measured clear distinction in Re^*_{tr}
  - Observed transition delay

$$\frac{T^*}{T_\mathrm{e}} = \frac{1}{2} + \frac{\gamma - 1}{2}\frac{\sqrt{\mathrm{Pr}}}{6} M_\mathrm{e}^2 + \frac{1}{2}\frac{T_\mathrm{w}}{T_\mathrm{e}}$$

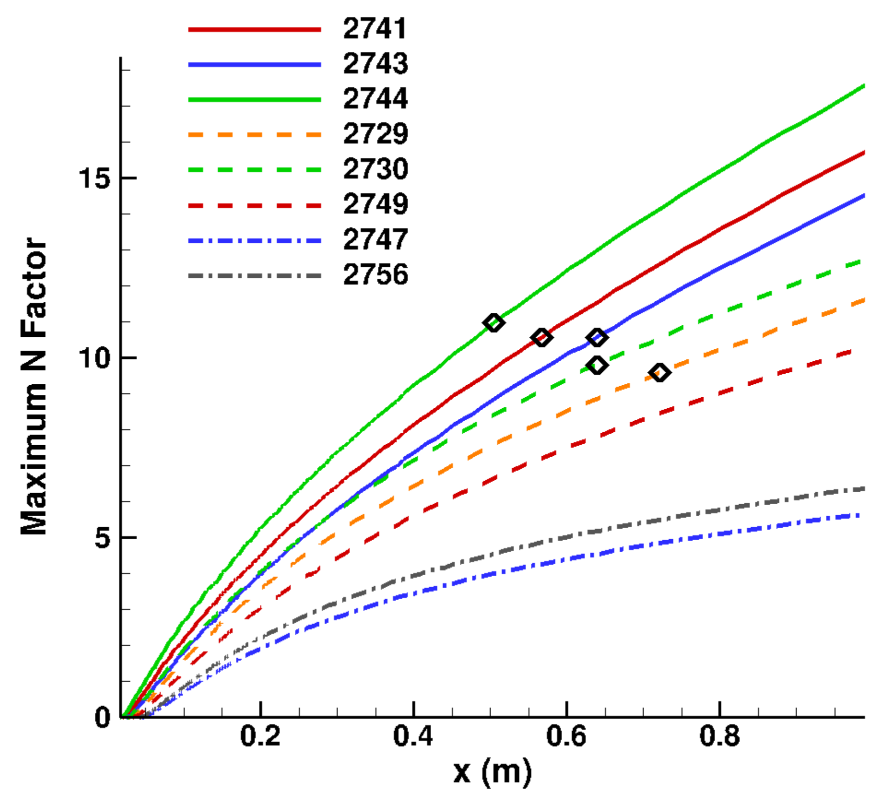
$$\mathrm{Re}^*_\mathrm{tr} = \frac{\rho^* u_\mathrm{e} x_\mathrm{tr}}{\mu^*}$$



Transition Reynolds number from experiments

Current Efforts

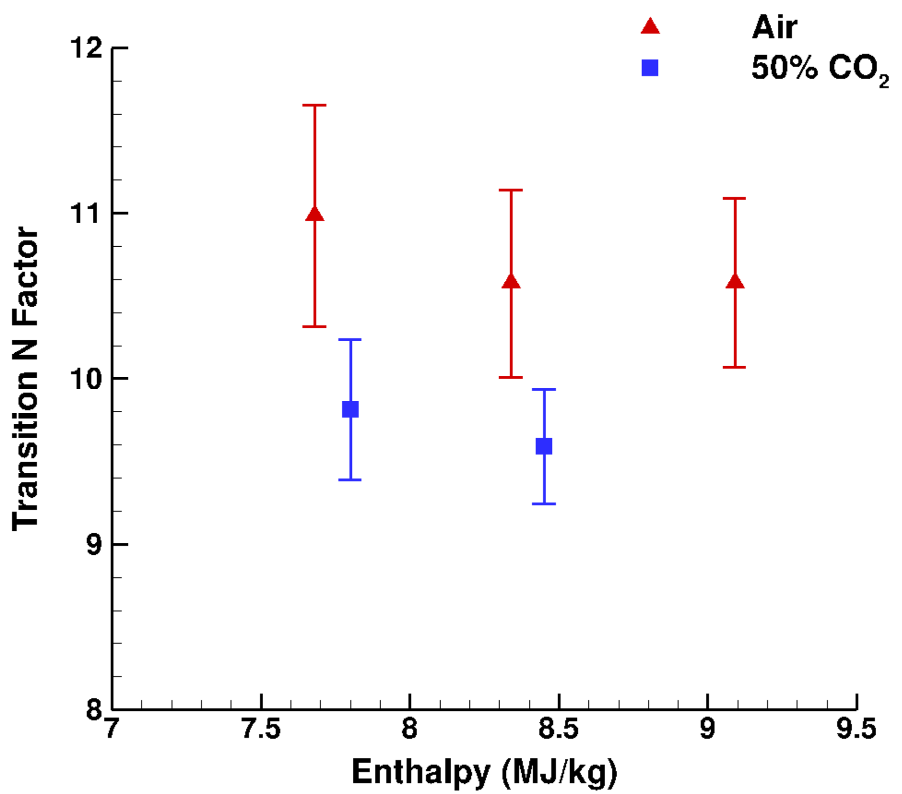
- Computational Analysis
  - Decrease in amplificatior with increase of CO_2
  - Consistent N_{tr} ~ 10
    - Range of freestream compositions
    - Range of Enthalpy



Computed max N factor for various T5 experiments

Current Efforts

- Computational Analysis
  - Decrease in amplification with increase of CO_2
  - Consistent $N_{tr} \sim 10$
    - Range of freestream compositions
    - Range of Enthalpy



Computed transition N factor* for various T5 experiments

*Error Bars indicate $\pm 4\ cm$.

Future Interests

- Apply this computational method to other high-enthalpy facilities
  - Do we see the same trends?
    - Gain confidence in modeling tools
    - Opportunity to improve modeling deficiencies
- Open to other high-enthalpy transition research

Questions/Comments?

- Referenced Papers:
  - Fujii, K. and Hornung, H.G. “Experimental Investigation of High-Enthalpy Effects on Attachment-Line Boundary-Layer Transition”. AIAA Journal. Vol. 41, No. 7, July 2003.
  - J. Jewell, I. A. Leyva, N. Parziale, and J. E. Shepherd. “Effect of gas injection on transition in hypervelocity boundary layers.” In Proceedings of the 28th International Symposium on Shock Waves, University of Manchester, July 17-22, 2011, 2011.
  - Jewell, J. S., Wagnild, R. M., Leyva, I. A., Candler, G. V., and Shepherd, J. E., “Transition Within a Hypervelocity Boundary Layer on a 5-Degree Half-Angle Cone in Air/CO_2 Mixtures”, AIAA Paper 2013-0523, January 2013

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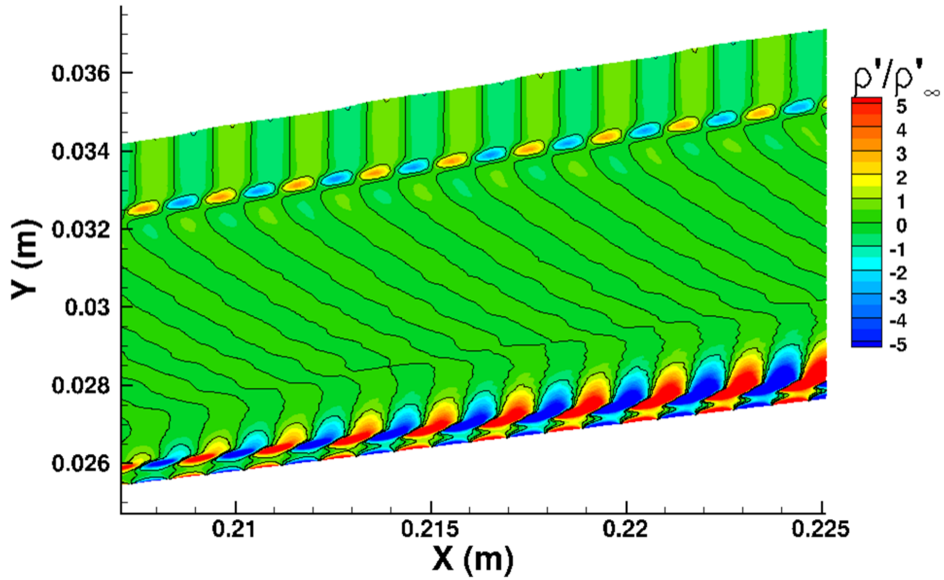
Vibrational Relaxation Effects on Acoustic Disturbances

- Geometry
  - 7° half-angle sharp cone
  - Nose radius $12.5\ \mu m$
  - Length $0.5\ m$
- Conditions
  - $h_0 = 4.6\ MJ/kg$
  - $Re = 2.6 * 10^7\ 1/m$
  - $Mach = 12.58$



Contours of density disturbance for the $1.4\ MHz$, slow wave case